



## Detection of Patent Foramen Ovale by 3D Echocardiography

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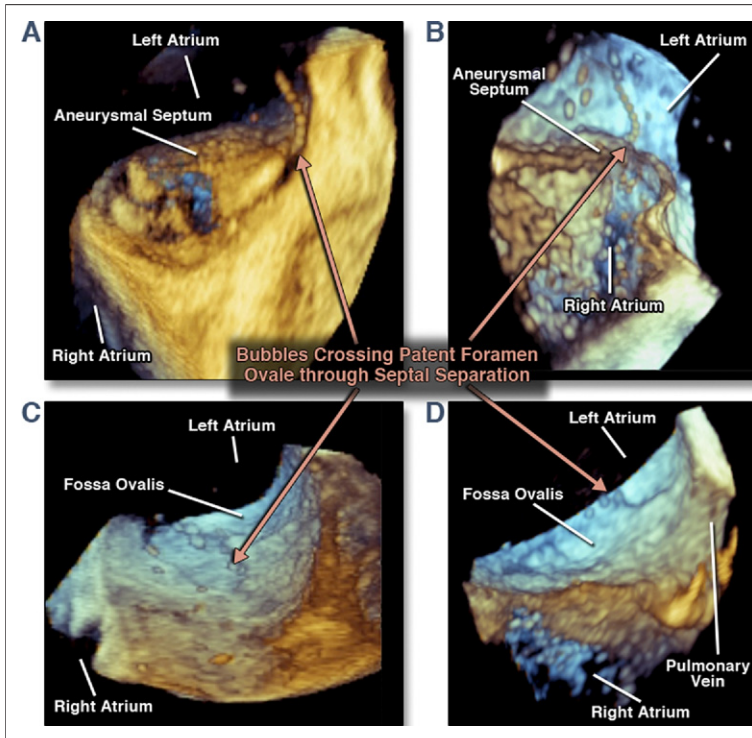
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**TECHNICAL ADVANCES IN PATENT FORAMEN OVALE (PFO) DEVICE CLOSURE RESULTED IN GREATER CLINICAL IMPORTANCE TO OPTIMALLY DIAGNOSE INTRACARDIAC SHUNTS.** Two-dimensional transesophageal echocardiography (2DTEE) with agitated saline contrast is currently the gold standard for diagnosing PFO. However, direct visualization of the bubbles crossing PFO through a septal separation is often difficult to capture by 2DTEE in a single imaging plane. Conventional 3-beat rule of bubble appearance in the left atrium after a complete right atrial opacification to differentiate PFOs from extracardiac shunts is unreliable. Valsalva maneuver often used to improve the detection of PFOs may be difficult to perform in the sedated patients during TEE. The advent of a real-time 3-dimensional transesophageal echocardiography (3DTEE) allowed direct visualization of the entire fossa ovalis and surrounding structures. It may potentially result in more accurate diagnosis of PFO by directly visualizing the bubbles crossing fossa ovalis.

We present images (Figs. 1, 2, 3, and 4) obtained from patients with cryptogenic stroke referred for routine 2DTEE to rule out cardiac sources of embolism. Agitated saline contrast was performed during 2DTEE and 3DTEE. High quality of 3-dimensional images suggested that 3DTEE is feasible. Unlike 2DTEE, 3DTEE provided detailed description of the entire PFO anatomy and surrounding structures and potentially higher degree of certainty in differentiating intracardiac from extracardiac shunts.

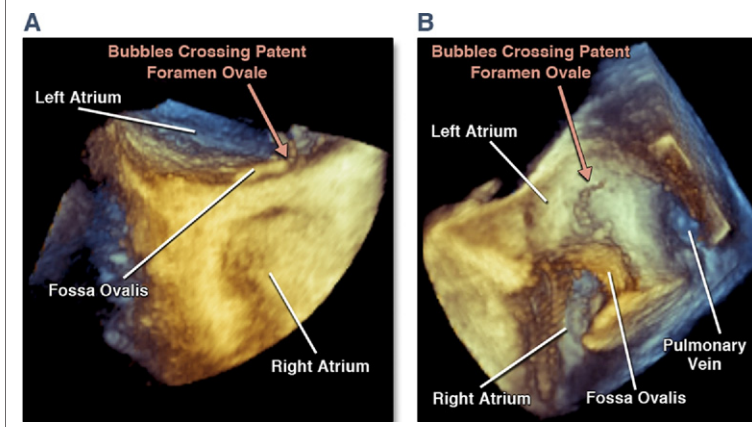
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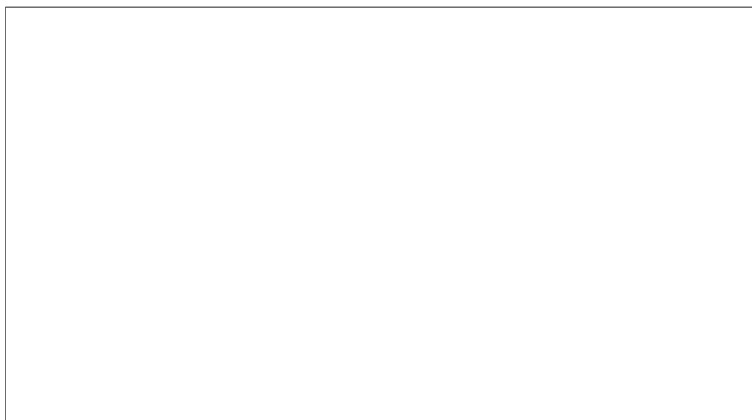
**Figure 1. Patent Foramen Ovale**

Three-dimensional transesophageal echocardiography views of the left and right atria and the atrial septum during agitated saline contrast injection are demonstrated from 4 different patients (A to D). The bubbles are directly shown entering the left atrium like a string of pearls (A and B) from the right atrium through the septal separation in the fossa ovalis (A to D). In addition, no bubbles are demonstrated entering the left atrium from the pulmonary vein (D; see Online Video 1) further supporting the diagnosis of patent foramen ovale (PFO) without a concomitant extracardiac shunt. The fossa ovalis has redundant aneurysmal tissue (A and B).



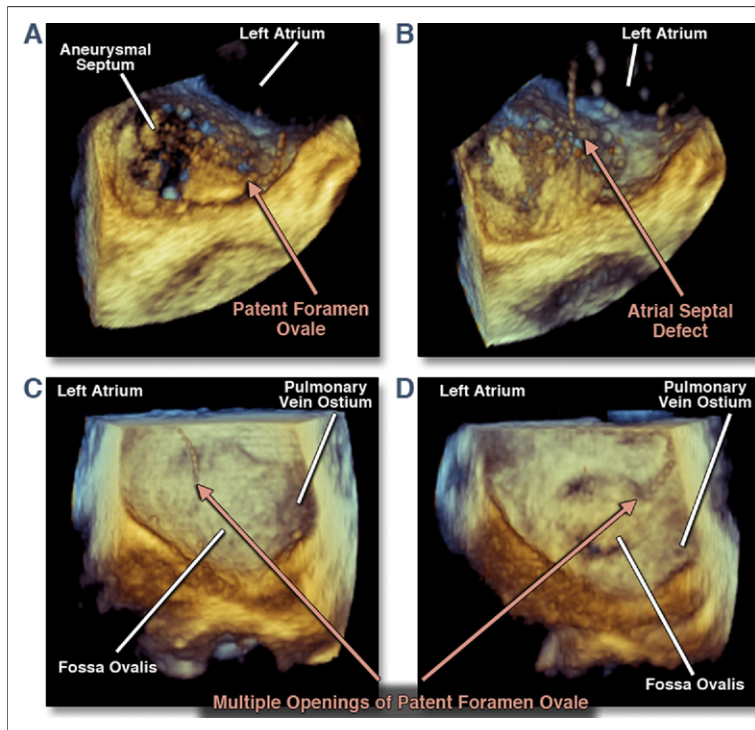
**Figure 2. PFO by 3D TEE**

Agitated saline contrast was injected during 3-dimensional (3D) transesophageal echocardiography (TEE) at rest. The bubble study was negative on 2DTEE whereas bubbles were demonstrated crossing PFO on 3DTEE (A; see Online Video 2). In another patient (B), the bubbles crossed the fossa ovalis beyond 3 cardiac cycles from complete opacification of the right atrium on 2DTEE, which may raise the possibility of an extracardiac shunt. On the other hand, 3DTEE clearly demonstrated the bubbles directly crossing fossa ovalis (B), whereas no bubbles appeared in the pulmonary vein (B; see Online Video 3). This suggests that 3DTEE may be more sensitive to detect PFO without a need for repeated contrast injections or Valsalva maneuver. Abbreviations as in Figure 1.



**Figure 3. Extracardiac Shunt**

Small bubbles (white interrupted circles) demonstrated on the 3-dimensional volumetric images of the left atrium (A and B) are visualized in en face view (B) as they enter the left atrium through the right upper pulmonary vein whereas no bubbles are seen crossing fossa ovalis (A and B; see Online Video 4), confirming an extracardiac shunt without a concomitant patent foramen ovale.



**Figure 4. Multiple Atrial Septal Defects**

Concomitant occurrence of PFO (A) and additional fenestration in the fossa ovalis (B) is demonstrated on 3DTEE images. In another patient (C and D) suspected of having hereditary hemorrhagic telangiectasia, 2 separate openings of PFO into the left atrium are demonstrated in en face views of the fossa ovalis (C and D), with the bubbles crossing the openings during different cardiac cycles. Compared with 3DTEE, this morphology is not easily appreciated on 2DTEE imaging. In addition, no bubbles entered the left atrium through the pulmonary vein, thus excluding an extracardiac shunt through arteriovenous malformations (C and D). Clinical relevance of multiple atrial septal defects that are easily recognizable by 3D imaging is particularly important in cases of planned device closures to ensure complete seal of the defect. Abbreviations as in Figures 1 and 2.

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#### APPENDIX

For Supplementary videos and their legends, please see the online version of this article.